Dynamic Integration of Mould Industry Analytics and Design Forecasting

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Abstract. The aim of this paper is concerned with a conceptual framework to get about the smart factory concept in the mould/tools industry, by retrieving knowledge from historical data and data analysis. Specifically, it will be addressed the requirements to design and develop the next generation of open decision making informatics systems as tools for high variability manufacturing systems as in the tooling industry. The proposed open computational platform as open informatics systems (I-systems) developed under the specifications of the conceptual framework mention above will combine new balancing and simulation algorithms that allow the optimization of the production systems suggesting new and credible collaborative production sequences in a forecasting manner. Coupling smart monitoring with real-time decision support I-systems, the proposed approach will be able to cope with the aim of reducing lead-times and costs on the shop floor. The proposed open system of systems approach aims at contributing to adaptive higher integration levels, contribute for a collaborative factory and, at the same time, reduce the vendor lock-in dependencies risks.

Keywords: Mould/tools industry · Dynamic integration · Co-operation · Collaborative organizations · Smart analytics · Self-learning

1 Introduction

The new industrial reality has brought up an increased complexity to the production structures, requiring new management and organization ways making them more flexible, agile, efficient and effective. This emergent reality implies that companies need to develop products and innovative engineering solutions that put them in a technology leadership [1]. This can be attained through the more efficient use of technologies and resources, practices and methods based on information intelligence [2]. It also depends on a founded strategy to manage complex business partnerships through making them prepared for collaboration in dynamic virtual organizations [11].

The products manufactured by the Engineering and Tooling industry are unique. This is an industry of small series and/or unit production. These companies have a large

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amount of data, improperly collected, that alone are just numbers, text and tables, humanly impossible to be analysed to generate knowledge. The collection, structure, compilation, analysis, sharing and monitoring of this data free of any contamination and its processing/interpretation in intelligible information, leading to what is called business intelligence, is of fundamental importance to facilitate decision making within the company [3]. For that purpose, there is a need to use smart monitoring systems on the factory shop floor, including distinctive functionalities for sensing, sensor networks, monitoring hardware and software, connected with manufacturing management and planning forecasting. Such smart systems require high levels of automation and information processing but allow quick reaction to changes on the shop floor. With this come new decision support tools sustained on Open Specification. Such tools should be able to support decision making based on the available data in a predictive or adaptive manner [4]. The approach proposed below combines new balancing and simulation algorithms that allow the optimization of the production system suggesting new and credible production sequences. The combination of smart monitoring and the real-time decision support system will cope with the aim to reduce lead-times and costs on the shop floor by the improvement of the flexibility of the manufacturing processes and by the increasing of the management control supported on new decision support tools based on smart analytics and self-learning [5]. The goal of this paper is to propose a conceptual framework to evolve the Smart Factory by retrieving knowledge from historical data and data analysis. Specifically, to design and develop the next generation Open Source decision making tool for high variability manufacturing systems: Allowing manufacturing decisions based on data reflecting the system past behaviour; Extracting knowledge from past data; Allowing performance measurement based on real-time data and performance evaluation based on manufacturing system status; Allowing risk analysis for more informed decisions and negotiations (with clients, suppliers, sub-contractors and other stakeholders involved); Allowing new Lean manufacturing methodologies responding to special requirements of Mould/Tooling Industry, such as waste reduction of all kinds, namely overproduction, holding time, unnecessary movements, transport, process, stock and defects, which can be translated into increasing productivity. Therefore, a service oriented cooperation enabled systems (CES) [12] is adopted as a modularity abstraction to reduce technology dependencies and empower modelling and intelligence capabilities.

Thus, the paper is organized as follows: Sect. 2 describes the challenges to be addressed to achieve the objectives mentioned above; Sect. 3 describes a conceptual framework for the development of mould/tool plant based on a smart factory concept; in Sect. 4 some conclusions are drawn.

2 Challenges to Be Addressed

Industrial globalisation created a new scenario for the Tooling industry, characterised by intense competition, short windows of opportunity in the market and frequent changes on ramp-up phases. Towards handling the mention challenges, this sector has been investing in technology and in the development of internal skills, both at the level of technological knowledge and in the investment market in terms of trying to identify opportunities and strategies to offer products and services of high technological intensity and with high standards of quality and innovation.

The long-term future impact of high performance computing power and communication speed, smart sensor technologies for generating and exploiting “big data”, the convergence of the embedded world and the Internet/Cloud world in cyber-physical systems (CPS), multi-modal visualization and interaction technologies, upon our society as a whole, will be the framework to make a wider variety of products available at reasonable prices combined with high levels of variety, customization, timeliness, newness and quality [6]. Hence, in addition to invest in new technologies, companies will need to develop new strategies for each business area; more flexible organizational structures designed to implement strategies based on timeliness, innovation and product augmentation; sophisticated policies for human resource management; different accounting systems; and financial analysis algorithms [7].

Based on advances in information and communication technologies (ICT) will be new ways for the manufacturing industries to serve society and a new style of competition in the global marketplace. Thus, since the traditional approaches of computer integrated manufacturing (CIM) will make the technology for achieving flexible, low-cost, high-quality production systems available to all competitors, the real competitive advantages will shift from production economies to innovation approaches – where the skills needed are as follows: identify a market niche and its special needs; design a “product/service” that will meet that need better than anyone else can meet it and in a way that is hard to copy; quickly design, produce and distribute the product, to be able to move onto the next product quickly; and to be able to manage the complexity of many different products and many different customers being served from the same facility and at the same time [7]. Firms will also need to change their concepts of strategic thinking - from a focus on products and markets to a focus on competitive advantage in terms of process technology and systems and the institutional learning that allows the companies effectively and efficiently utilized advanced technology [8].

Aiming to achieve competitive advantages the new CIM approaches should be based on advanced analytics and smart decision support systems with self-learning capabilities exploiting the availability of “big data” from smart sensors, historical process files, or human-authored data; and addressing aspects, e.g. interactivity, real-time, data-fusion, imprecise computing, compressed sensing, advanced visualization, security, and privacy [9], ensuring coordination and collaborative activities involving many performers. Coordination and collaboration can be achieved in many ways. Integration is one of them, which means unity, connection, and interrelationships between elements and processes of a given manufacturing structure. In management processes, an especially important role is played by the flow of information between participants of an organization. Information media include technical means and people. The problems consist in the rational division of functions between the people and the machines, as well as a correct way of integration (co-operation and collaboration) of the people and the machines. Technical and social integration create an integrated manufacturing environment.

Between other types of one-of-a-kind product (OKP) manufacturing industries, a typical OKP company can be an injection mould/tool manufacturer. However, in injection mould/tool manufactures, due to a high customization involving uncertainties, resulting in a lot of reworking, the product development cost is normally higher and the development lead time is longer than in product-focused manufacturing companies. Anyway, in a smart factory, the rapid development of an OKP will be a holistic organizational concept that describes the development process by combining and integrating various innovative technologies and tools, such as rapid manufacturing (e.g. 3D printing), computer supported cooperative and collaborative tools and a supportive environment. Furthermore, an injection mould/tool manufacturing company pose some challenges to the factory of the future that could be characterized as follows: high customization; successful product development and production in one go; optimal or rational utilization of technologies and resources; adaptive production planning and control; continuous customer influence throughout the production; distributed control and inter-organizational autonomy. Thus, aiming to cope with the above-mentioned challenges the following section presents a conceptual dynamic integration framework concerned with a smart factory concept to the mould/tools industry.

3 Conceptual Dynamic Integration System

Moulds manufacturing are highly variable systems, often OKP production. These complex and engineering ordered products require dynamic engineering but face low levels of processes standardization. This leads to difficulties in planning and control that might yield high discrepancies between initial planning and execution. Manufacturing data from the past exist but does not talk with the manufacturing system in the sense that no (very little) information is retrieved from history. The conceptual approach proposed here aims to define a framework for the development of a new system fed by real-time data from smart sensors. Thus, it should be considered the integration of knowledge-based systems covering the complete product life-cycle with advanced analytics, smart decision support systems with self-learning capabilities exploiting the availability of “big data” from smart sensors, historical process files, or human-authored data, addressing aspects, such as interactivity, real-time, data-fusion, imprecise computing, compressed sensing, advanced visualization, security, and privacy. Hence, the authors’ proposed approach is focused on how to establish a clear evolution from the current tacit culture (predominant) to an informed/founded factory (reasoned factory) where workers have the efficient tools, and, thus, we strategically shift the name for informatics systems (I-systems) an open structuration of computational responsibilities [13], aiming to help them to decide. Such I-systems deeply depend on heterogeneous data sources that require effective and simple interaction views to be accessible by factory workers helping them to decide accurately. This requires the collection of real-time data from a diversity of proveniences (mould components, machines, cells, legacy systems, and tools), integrated and dispatched to specialized decision making computational systems (services) in a complex fusion of data from disparate sources and in a diversity of formats. Furthermore, such web of heterogeneous data needs a transformation to be accessed by factory persons in a simple and clear way, through coordinated decision making tools suite (consistently integrated). The proposed decision-making tools should deal with the failure and with incomplete data by presenting useful and accurate results.

Hence, addressing the challenges mentioned above and aiming to contribute to the concept of a smart factory in the injection mould/tools industry, a conceptual, computational framework is presented. Such an approach is concerned with the development of a supervision and control system based on an open platform, designed to cooperate and collaborate with other systems of an organization through a bus service. The computational platform itself concerned with the mould/tool process supervision and control, should be based on an open service-oriented architecture (SOA) as a network of I-systems, services, and devices with a dynamic interconnection based on a "plug and play" logic and standard interfaces. All elements of overall integrated system are structured as adaptive and discoverable entities abstracted through the CES model independently if they embed simple computational or cyber-physical parts [12]. The challenge starts from the question that considers an open architecture for a supervision and control system, service oriented, as the best strategy for an agile solution, flexible, secure, adaptive and autonomic. Each service corresponds to an autonomous computational entity, which could be an intelligent agent, having an autonomic response to the resolution of exceptions with the guarantee of the service quality level required. Furthermore, the supervisory and control production system interconnects to the organization's service bus providing a set of services to other legacy systems (ERP, CRM, BI). The adoption of a cooperative and collaborative approach to the system development requires the implementation of open interfaces. Considering the complexity of a factory landscape, in special for the cases where it is very challenging to collect accurate real-time data, e.g. the mould production shop-floor, the strategy is to develop complementary approaches for data acquisition. On the one hand, the association of a transponder (as a thing) able to supply real-time data about a piece position and status (and potentially with some local intelligence). On a complementary approach, 3D vision should be used to interpret shop-floor areas and complement (fuses) the data for an accurate decision making.

On the other hand, the high product variability observed in the moulds industry together with the time shortened product-life-cycles require agile and flexible production environments, which can be adapted rapidly to new product demands. This degree of flexibility cannot be achieved by traditional process automation approaches. Instead, modular factory structures composed of smart devices – the so-called CPS – establishing an Internet of Things (IoT), are key elements to overcome the current rigid planning and production processes [10]. Thus, to successful achieve highly modular factory infrastructures it should be based on multi-vendor automation interoperable technology. Thus, the core focus of the conceptual proposed approach is on the Dynamic Integration System (DIS) that combines input from a Data Acquisition Systems (DAS) and available Open Specified I-systems. Both DAS and DIS will include aspects of Big Data, especially data with various origins and formats, such as built-in sensors, manual input, quality control protocols, and customer feedback, etc. Thus, the DIS approach and the corresponding main key features are depicted in Fig. 1. The system here proposed can collect data from smart sensors attached to each part or component giving continuous information about the location, resources, operation time, and setup time, among other. All this information will be used to create new knowledge about the design and manufacturing phases and will be stored on databases and historical data. The smart analytics of the DIS will include machine learning approaches to improve the suggestions for actions and their impact on the process chain.

Key Features

- Reference models/tools for data collection;
- Smart sensors for machines and products/parts;
- Data structures for historical data;
- Models for data analysis and process optimization; Human-Machine Interaction for collecting human-authored data and provide instructions;
- Manufacturing Execution System (MES) integration;
- Cloud based infrastructure for (near) real-time monitoring and feedback;
- Methodologies for data collection and data analysis.

Fig. 1. The Dynamic Integration System conceptual framework.

DIS is the formulation of a strategy towards the establishment of a digital collaborative factory as an open community of open informatics systems able to cooperate for intelligent factory services. The approach considers both an intra-factory and an inter-factory integration of the informatics systems. It ranges from cyber-physical systems as specialized bridges between the physical and the computational world [14], to informatics systems managing collaborations. The bridge is made through a special CES component targeted to abstract specific shop floor equipment and sensors interacted based on proprietary protocols or even if standards are adopted as implementations might differ at some interaction level (wire, data payload format, semantic model or coordination), as depicted in Fig. 2.

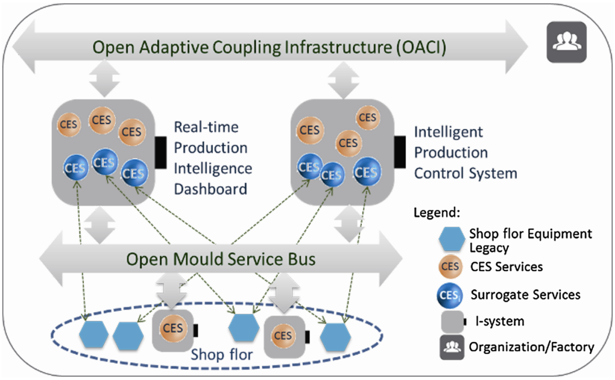

Fig. 2. The two-layered open service bus based on the CES model.

The proposed approach follows the CES adaptive framework model where a computational entity is developed for the cooperation [12]. The CES services components are structured as I-systems as a minimal instantiation (deploy) grouping a set of CES components. The proposed model accommodates the evolution of legacy systems or shops floor cyber-physical systems/equipment. The special surrogate CES components also depicted in Fig. 2, play a bridge role between making this way possible a smooth evolving migration to the new open informatics systems framework. The surrogate abstraction mechanism is a transitory mechanism considering that when all the shop-flor evolve for the adoption of the open CES model, the adaptation role is not anymore necessary. This way, the proposed model makes possible a convergence for the novel, innovative Informatics systems (I-systems) to be developed under independent and possibly multi-supplier dynamics. Furthermore, the new generation of shop floor equipment, if CES enabled, can simplify their internal computational capabilities and complement intelligence with CES running on-premises or in the cloud as cooperative autonomous services. Some of them can inherit from the Intelligent Agents achievements by embedding (business or control) intelligence capabilities.

In addition, for the mould industry to answer the crescent collaborative dimension requiring the exchange of data in different formats and size among partners, the Enterprise Collaborative Network (ECoNet) platform [15] is adopted. The ECoNet platform aims at structure the business to business relations under a common multiple formats data exchange and integrated/coordinated mechanisms. It replaces the current adaptation chaos that contributes for a tight coupling between I-systems from business partners, potentially developed under different processes and technological cultures. The proposed open adaptive coupling infrastructure (OACI) as a loose coupling strategy based on the CES and I-systems concepts, unifies the computational infrastructure of the factory of the future making this way possible to separate (decouple) intelligent processes sharing a common distributed computational infrastructure (security, coordination, fault tolerance, scalability, reliability quality of services, and costs moderation by a multi-supplier model). The possibility to establish hybrid computational execution environments on premises, and on the cloud, in line with the microservices dynamics [16], makes our approach scalable (elasticity) and prone (open) for novel intelligent services and added value composites (integrated business intelligence applications).

4 Conclusions

The continuous competitiveness of the Tooling industry is determined by the ability to understand and respond quickly to the needs of its customers associated with the capacity to reformulate their manufacturing systems to achieve gains in cost, quality and performance and delivery times. This goal involves the adoption of new and better technologies supported by improved management tools allowing higher performances on manufacturing, higher competitiveness, and sustainability of the companies. The Open Source decision-making tools will have the ability to see the preceding and work in process, and to simulate the working charge and resources balance, giving fundamental information that will help to reduce the time from design to manufacturing. Such a computational platform will improve the cooperation with the customer, by the possibility of having a faster answer to customer´s demands and modifications and its implications on shop floor planning. Through this tool, the customer will have access to all information related to the work in process. Furthermore, it will provide important information to improve the balance of the resources and work in process, even with new changes and modifications promoted by the client, because these changes could implicate a new balance and distribution of resources. By implementing this new tool, it is expected to achieve the following benefits for moulding/tooling industry: Real-time data collection during tool production used to optimise and standardise the tool production process; Improve tool maintenance procedures (adaptive preventive maintenance); Improve tool total value and decrease total costs; Improved cost efficiency and accuracy, reliability and speed of simulation techniques for manufacturing processes and/or full complex products.

A concept prove is planned to be implement in a near future, in a mould/tool manufacturer shop floor, based on the conceptual framework described in this paper.

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